On Colocation of 3GPP Long Term Evolution Systems

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ABSTRACT

To ensure LTE systems can coexist with other mobile systems operating in the same geographical area, or the LTE Base Station (BS) can be collocated with other mobile system BSs, coexistence studies for LTE with other systems have been carried out in 3GPP. In this article, we provide an overview of the coexistence studies that have been done. First we list the terminologies that are commonly used for coexistence studies, and explain how deterministic analysis can be done for the BS to BS interference scenario. Then we provide the system simulation methodology and assumptions used in the coexistence studies, and show some simulation results for the possible impacts with different system parameters. Finally we provide the references to the 3GPP standards where the LTE BS and UE radio transmission and reception requirements are specified to facilitate LTE coexistence with other mobile systems.

INTRODUCTION

The first release of the Long Term Evolution (LTE) standards was targeted to be completed in the Third Generation Partnership Project Radio Access Network (3GPP RAN) by early 2009, and the commercial deployment is expected to start as early as 2009. During the initial roll-out of LTE networks, it is anticipated that LTE would be deployed as an overlay of the operators' existing second generation (2G)/third generation (3G) mobile networks. This is because currently there is no dedicated frequency spectrum allocated for LTE use, and the operators would gradually migrate the spectrum use from 2G/3G to LTE use, in order to enhance the broadband data capacity of their networks while maintaining sufficient services on their 2G/3G networks. Consequently, it is essential to ensure that the LTE system can coexist with other anticipated mobile systems (GSM, CDMA, Universal Mobile Telecommunications System [UMTS], etc.) operating in the same geographical area, or the LTE base station (BS) can be collocated with other system BS, especially those operating in the adjacent frequency spectrum. This means that the coexisting systems will not significantly degrade the performance (in terms of capacity, availability, etc.) of each other.

In 3GPP RAN Working Group 4, coexistence of LTE with other mobile systems has been studied using system scenarios, together with implementation issues, that reflect the environments in which LTE is expected to operate, and the LTE radio transmission and reception characteristics have been specified accordingly to facilitate LTE coexistence with other mobile systems. In this article we give an overview of the coexistence studies between LTE and other mobile systems, focusing on the work that has been done in 3GPP RAN Working Group 4 during the LTE standardization process. We first provide an overview of the basic terminologies for coexistent studies. We then introduce how a deterministic analysis could be done, followed by a discussion of simulation assumptions and results for some LTE coexistence scenarios. Then we list 3GPP requirements specified in RAN Working Group 4 to ensure smooth coexistence between LTE and other mobile systems. We provide our conclusions in the final section.

BASIC TERMINOLOGIES

Here we introduce the basic terminologies that are commonly used in coexistence studies.

Minimum Coupling Loss — Minimum coupling loss (MCL) gives the minimum loss in signal power between a transmitter and a receiver, and is defined as the minimum path loss (including antenna gains and cable loss) measured between the transmitter and receiver Equipment Antenna Connector (EAC).

Antenna Isolation — To ensure two coexisting transmission systems will not cause too much harmful interference to each other, we need to ensure there is sufficient antenna isolation between them. Antenna isolation is defined as the path loss (including antenna gains, cable losses, and propagation loss through the air) from an interfering transmitter EAC to an affected receiver EAC. The antenna isolation requirements are usually derived by the following criteria:

- The interfering transmitter out-of-band (OOB)/spurious emission received by the affected receiver is sufficiently below the affected receiver noise floor.
- The affected receiver 3rd order inter-modulation product (IMP) caused by two inter-

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fering carriers is sufficiently below the affected receiver noise floor.

- The total interfering carrier power attenuated by the affected receiver radio frequency (RF), intermediate frequency (IF), and baseband filters is sufficiently below the affected receiver noise floor.
- The total interfering carrier power attenuated by the affected receive filters is sufficiently below the affected receiver 1 dB compression point.

Typically, the isolation guideline between System 1 and System 2 is equal to the maximum of the isolation estimate from the System 1 transmitter to the System 2 receiver, and the isolation estimate from the System 2 transmitter to the System 1 receiver.

Noise Floor — There is some background noise inherent in the receiver. This is dependent on the bandwidth and the intrinsic temperature of the receiver. The level of this noise is referred to as the noise floor. It generally sets the lower bound of the receiver performance.

OOB/Spurious Emission — OOB/spurious emissions are unwanted emissions outside the transmit band (resulting from the modulation process and non-linearity in the transmitter) observed in the receive band.

Receiver 3rd Order IMP — IMP is any intermodulation product that is created at the receiver due to any order of mixing of primary communication carriers/tones. Usually the 3rd order IMP are the strongest tones that fall in the receive band.

Receiver Sensitivity — The reference sensitivity level is the minimum mean desired signal power received at the receiver antenna connector at which certain performance criteria (e.g., bit error rate or throughput) shall be met.

Receiver Desensitization — This is defined as the degradation in the receiver sensitivity due to an increase in the receiver noise floor by the interfering OOB/spurious emission or IMP. The most significant case is when the transmit band of the interfering system is adjacent to the receive band of the victim system, where the interfering OOB (referred to as adjacent channel interference) will be largest.

Receiver Blocking — Blocking occurs when the interfering carrier power passing through the affected receiver filtering including RF filter, IF filter, and base-band responses, is high enough such that the affected receiver cannot maintain the reference sensitivity or cannot detect a low desired signal power.

Receiver Overload — This is caused by a signal at the receiver EAC that is too strong. When a receiver is driven into overload, its amplification gain is depressed. A receiver performance parameter known as the 1 dB-compression point determines when the receiver will overload.

Adjacent Channel Leakage Power Ratio — Adjacent channel leakage power ratio (ACLR) is defined as the ratio of the transmitter mean power centered on the assigned channel frequency to the mean power centered on an adjacent channel frequency. ACLR provides the amount of interference that a transmitter could cause to a receiver operating in the adjacent channel.

Adjacent Channel Selectivity — Adjacent channel selectivity (ACS) is defined as the ratio of the receive filter attenuation on the assigned channel frequency to the receive filter attenuation on the adjacent channel frequency. ACS is a measure of the receiver's ability to receive a wanted signal in the presence of an adjacent channel signal.

Adjacent Channel Interference Ratio — Adjacent channel interference ratio (ACIR) is defined as

$$ACIR = \frac{1}{\frac{1}{ACLR} + \frac{1}{ACS}} \qquad (1)$$

ACIR is a measure of the total interference caused by a transmitter to an adjacent channel receiver, due to the imperfection of the transmitter filters to filter the OOB emission and the receiver filters to attenuate the adjacent channel signal.

Performance Metric — The metric for the degradation of a victim system by the presence of an interfering system on adjacent channel is usually specified as the voice capacity loss or data throughput loss.

DETERMINISTIC ANALYSIS

The BS to BS interference case for coexisting BS (in the same geographical area or co-sited) could be studied using deterministic analysis, since the BS positions are fixed and in the worst case they transmit at full power most of the time. For example, in order to protect a LTE frequency division duplex (FDD) BS receiver from being desensitized by emissions from a co-sited LTE time division duplex (TDD) BS transmitter operating at another frequency, the following analysis gives the required OOB/spurious emission limit from the interfering transmitter to the victim receiver. Here we assume 9 MHz receive bandwidth (90 percent utilization for 10 MHz channel bandwidth), 60 dB antenna isolation between the transmitter (Tx) and receiver (Rx) EAC, 5 dB noise figure, and 0.8 dB desensitization:

Receiver noise floor = –174 dBm/Hz
+ 10log (9e6)dBHz + 5 dB = –99.5 dBm

Interference level below noise floor
= $10\log[1/(10^{0.8/10} - 1)]$ dB = 7 dB

Interference level at receiver EAC
= –99.5 dBm – 7 dB = –106.5 dBm

Interference level at transmitter EAC
= –106.5 dBm + 60 dB = –46.5 dBm

Thus the OOB/spurious emission limit from the transmitter into the receive bandwidth shall be –46.5 dBm/9 MHz = –66 dBm/100 kHz.

Besides, we can derive the LTE FDD BS receive filter rejection required to prevent receiver blocking. Assuming a 46 dBm LTE TDD BS transmit power, we obtain that the required LTE FDD BS receiver selectivity should be 46 dBm – 60 dB – (–106.5 dBm) = 92.5 dB.

In 3GPP RAN Working Group 4, coexistence of LTE with other mobile systems has been studied using system scenarios, together with implementation issues, that reflect the environments in which LTE is expected to operate.

System simulation is required for coexistence studies on the interference cases involving user equipment. This is because the UE positions are not fixed and they are not expected to transmit with full power most of the time due to power control.

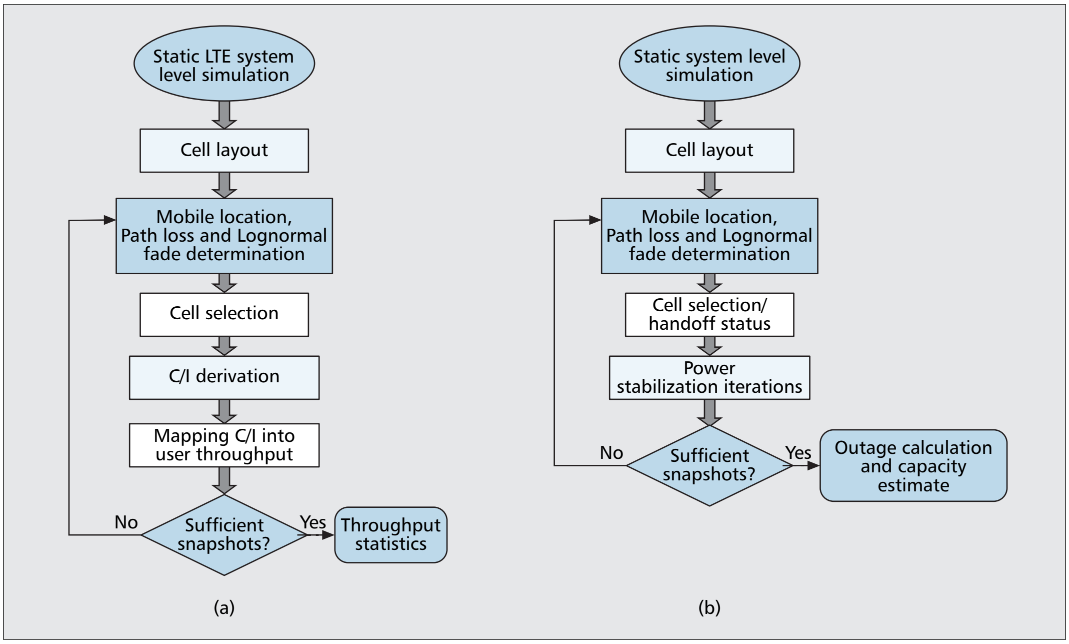


Figure 1. *Simulation flowcharts: a) LTE; b) UMTS.*

SYSTEM SIMULATION

System simulation is required for coexistence studies on the interference cases involving user equipment (UE), i.e., BS_UE, UE_BS, UE_UE. This is because the UE positions are not fixed and they are not expected to transmit with full power most of the time due to power control. Hence using deterministic analysis could result in findings that are too conservative, which in turn lead to unnecessarily tight coexistence requirements.

In this section we provide an overview of the system simulation that has been performed in 3GPP RAN Working Group 4 for the coexistence studies between LTE and UMTS. First we describe the simulation assumptions and parameters used in the studies. Then we provide some simulation results to show the system performance with different parameter settings.

SIMULATION FLOWCHART

The simulation flowcharts for a LTE system and a UMTS system are shown in Fig. 1.

As a quick summary, static simulation snapshots are performed to obtain LTE interference and LTE data throughput based on the LTE link level simulation results for carrier-to-interference ratio (C/I) versus throughput. Inputs include ACIR and other system parameters, which are described in more detail below, and outputs include the impact of LTE interference on LTE average and 5 percent CDF throughput.

An outage for a UMTS user occurs when, due to a limitation on the maximum Tx power, the achieved E_b/N_0 of a connection is lower than the E_b/N_0 target –0.5 dB. And the UMTS system capacity is obtained as the number of satisfied users, having the achieved E_b/N_0 of a connection at the end of a snapshot higher than a value equal to E_b/N_0 target –0.5 dB. For 8 kb/s speech service, the downlink (DL) and uplink (UL) E_b/N_0 targets are assumed to be 7.9 dB and 6.1 dB, respectively [1].

CELL LAYOUT

For uncoordinated network simulations, the worst inter-system site shifting case (where the UMTS sites are located at the edge of the LTE cell coverage) is assumed. Here an interfering UE could be at the cell edge of its serving BS (and thus transmitting with the highest power) but very close to the victim BS (and thus causing the highest interference). The cell layout is shown in Fig. 2.

ANTENNA RADIATION PATTERN

The UE antenna radiation pattern is assumed to be omni-directional.

The BS antenna radiation pattern, assumed for each sector in 3-sector cell sites, is given by:

$$A(\theta) = -\min\left[12\left(\frac{\theta}{\theta_{3dB}}\right)^2, A_m\right] \quad \text{where } -180 \le \theta \le 180 \tag{2}$$

where θ_{3dB} = 65 degrees is the 3 dB beam width, and A_M = 20 dB is the maximum attenuation.

PROPAGATION MODELING

For macro-cell deployment in urban or suburban areas, the urban propagation model is used:

$$L(R) = 40*(1 - 0.004*DHb)*\mathrm{LOG10}(R) - 18*\mathrm{LOG10}(DHb) + 21*\mathrm{LOG10}(f) + 80 \text{ dB} \tag{3}$$

where *DHb* is the BS antenna height above average building top, *f* is the frequency in MHz, and *R* is the distance between BS and UE in km.

Considering a carrier frequency of 2 GHz and a BS antenna height of 15 m above average rooftop level, the propagation model is given by:

$$L(R) = 37.6*\ \mathrm{LOG10}(R) + 128.1 \tag{4}$$

The path loss from a transmitter EAC to a

receiver EAC (including both antenna gains and cable losses) is determined by:

$$\text{Path\_Loss} = \max(L(R) + \text{Log\_normal\_Fading} - \text{G\_Tx} - \text{G\_Rx}, \text{Free\_Space\_Loss} + \text{Log\_normal\_Fading} - \text{G\_Tx} - \text{G\_Rx}, \text{MCL}) \quad (5)$$

where G_Tx is the transmitter antenna gain in the direction toward the receiver antenna, taking into account the transmitter antenna pattern and cable loss; G_Rx is the receiver antenna gain in the direction toward the transmitter antenna, taking into account the receiver antenna pattern and cable loss; Log_normal_Fading is the shadowing fade following the log-normal distribution, assuming a 10 dB standard deviation; and MCL is assumed to be 70 dB in an urban or suburban macro-cell case.

ACIR Modeling

For LTE DL a common ACIR for all frequency resource blocks (RB) is used [2].

For LTE UL it is assumed that the ACIR is dominated by the UE ACLR, and the UE ACLR is assumed to be larger when the allocated RBs for interfering UE and victim UE are not adjacent to each other. The UE ACLR models are depicted in Tables 1 and 2.

Power Control Modeling

For LTE DL, no power control is used, and fixed power per frequency RB is assumed.

For LTE UL, the following power control equation is used:

$$P_t = P_{\max} \times \min\left\{1, \max\left[R_{\min}, \left(\frac{PL}{PL_{\text{x-ile}}}\right)^{\gamma}\right]\right\} \quad (6)$$

where $P_{\max}$ is the maximum transmit power, $R_{\min}$ is the minimum power reduction ratio to prevent UEs with good channels to transmit at very low power level, PL is the path loss for the UE, $PL_{\text{x-ile}}$ is the x-percentile path loss (plus shadowing fade) value, and $0 < \gamma < = 1$ is the balancing factor for UEs with bad channel and UEs with good channel. Note that this means the x percent of UEs that have the highest path loss will transmit at $P_{\max}$.

Also two parameter sets, provided in Table 3, are specified to show the possible impacts of different LTE UL power control algorithms [2].

Assumptions and Parameters

The other simulation assumptions and parameters are summarized in Table 4 [2].

Simulation Results

We now present some simulation results using the simulation methodology and assumptions described above for the 5 MHz LTE FDD – 5 MHz UMTS FDD (victim) scenario, and for the 10 MHz LTE FDD – 10 MHz LTE FDD (victim) scenario.

The simulation results for DL capacity loss versus ACIR with LTE BS interference are shown in Fig. 3. The UMTS FDD (8 kb/s speech system) DL capacity loss versus ACIR for the scenario where the 5 MHz LTE BSs interfere with the UMTS UEs is shown in Fig. 3a. It is observed that with 25 dB ACIR, the UMTS capacity loss is about 6.7 percent; if the ACIR increases to 30 dB, the UMTS capacity loss becomes about 2.3 percent. Based on the existing UMTS FDD technical specifications, the ACIR could be dictated by the UMTS UE receiver ACS of 33 dB. Therefore, the associated UMTS DL capacity loss caused by LTE BS interference might be less than 3 percent.

The LTE DL throughput loss versus ACIR for the scenario where 10 MHz LTE BSs interfere with the 10MHz LTE UEs is shown in Fig. 3b. Both 5 percent CDF and average user throughput degradations are presented. It is observed that with 25 dB ACIR, the LTE 5 percent CDF throughput loss is about 17 percent and the aver-

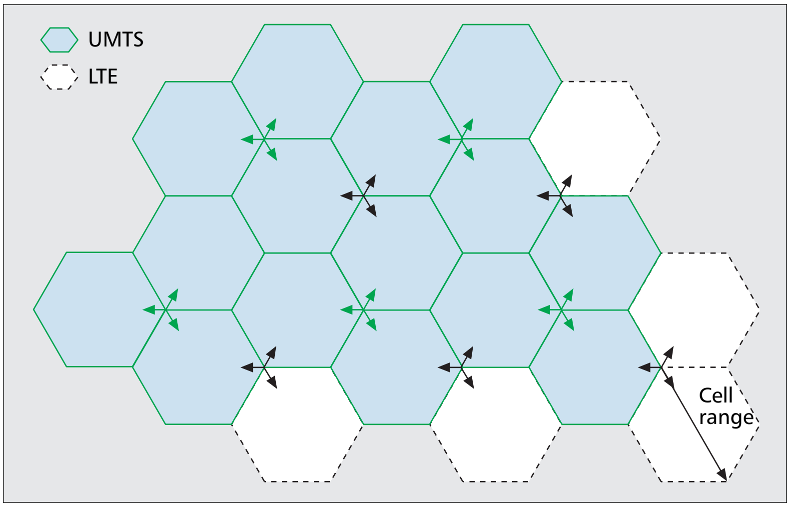


Figure 2. *Uncoordinated UMTS/LTE cell layout.*

Location of aggressor 4 RBs	Adjacent to victim channel edge	At least 4 RBs away from channel edge
ACLR dBc/3.84 MHz	30 + *X*	43 + *X*
X serves as the step size for simulations, *X* = … –10, –5, 0, 5, 10 … dB		

Table 1. *ACLR model for 5 MHz LTE interferer and UMTS victim.*

LTE	No. of RBs per UE	Bandwidth ($B_{\text{Aggressor}}$)	ACLR dB/$B_{\text{Aggressor}}$	
			Adjacent to edge of victim RBs	Non Adjacent to edge of victim RBs
5 MHz	4	4 RB	30 + *X* (less than 4 RBs away)	43 + *X* (more than 4 RBs away)
10 MHz	8	8 RB	30 + *X* (less than 8 RBs away)	43 + *X* (more than 8 RBs away)
15 MHz	12	12 RB	30 + *X* (less than 12 RBs away)	43 + *X* (more than 12 RBs away)
20 MHz	16	16 RB	30 + *X* (less than 16 RBs away)	43 + *X* (more than 16 RBs away)
X serves as the step size for simulations, *X* = … –10, –5, 0, 5, 10 … dB				

Table 2. *ACLR model for LTE interferer and 10MHz LTE victim.*

age throughput loss is about 4 percent; if the ACIR increases to 35 dB, the LTE 5 percent CDF throughput loss becomes about 3 percent and the average throughput loss is about 1 percent.

The simulation results for UL capacity loss vs. ACIR offset with LTE UEs interference are shown in Fig. 4. The average UMTS FDD (8 kb/s speech system) UL capacity loss versus ACIR offset (*X* in Tables 1 and 2) for the scenario where 5 MHz LTE UEs interfere with the UMTS BSs is shown in Fig. 4a. For power control set 1 ($\gamma = 1$, $PL_{x\text{-ile}} = 115$ dB), it is observed that with 0 dB ACIR offset, the UMTS capacity loss is about 45.3 percent; if the ACIR offset increases to 15 dB, the UMTS capacity loss becomes about 1.3 percent. For power control set 2 ($\gamma = 0.8$, $PL_{x\text{-ile}} = 133$ dB), it is observed that with 0 dB ACIR offset, the UMTS capacity loss is about 3.0 percent; if the ACIR offset increases to 5 dB, the UMTS capacity loss becomes about 0.9 percent.

The 10 MHz LTE FDD UL throughput loss versus ACIR offset (*X* in Tables 1 and 2) for the scenario where 10 MHz LTE UEs interfere with the 10 MHz LTE BSs is shown in Fig. 4b. The impact is given in both average throughput loss and loss at the 5 percent CDF throughput. For power control set 1 ($\gamma = 1$, $PL_{x\text{-ile}} = 115$ dB), it is observed that with 0 dB ACIR offset, the LTE capacity loss is about 2.1 percent; if the ACIR offset increases to 5 dB, the LTE capacity loss becomes about 0.8 percent. For power control set 2 ($\gamma = 0.8$, $PL_{x\text{-ile}} = 133$ dB), it is observed that with 0 dB ACIR offset, the LTE capacity loss is about 1.3 percent; if the ACIR offset increases to 5 dB, the LTE capacity loss becomes about 0.5 percent.

Parameter set	Gamma	$PL_{x\text{-ile}}$			
		20 MHz bandwidth	15 MHz bandwidth	10 MHz bandwidth	5 MHz bandwidth
Set 1	1	109	110	112	115
Set 2	0,8	—	—	129	133

Table 3. *Uplink power control parameter sets.*

Carrier frequency	2 GHz
Cell layout	Wrap-around 36 tri-sector cells, uncoordinated
Cell range	500 m
Lognormal fade correlation coefficient between sectors at the same site	1
Lognormal fade correlation coefficient between different sites	0.5
LTE/UMTS BS antenna gain	15 dBi
LTE/UMTS UE antenna gain	0 dBi
LTE/UMTS BS noise figure	5 dB
LTE/UMTS UE noise figure	9 dB
Maximum LTE BS transmit power	43 dBm for ≤ 5 MHz carrier, 46 dBm for ≥ 10 MHz carrier
Maximum UMTS BS transmit power	43 dBm
Maximum LTE UE transmit power	24 dBm
Maximum UMTS UE transmit power	21 dBm

Table 4. *Simulation assumptions and parameters.*

3GPP Requirements

With the findings from the coexistence studies, also considering the implementation issues, certain requirements for LTE BS and UE transmitter and receiver have been specified in 3GPP RAN Working Group 4 to facilitate the coexistence of an LTE network with other mobile systems. The transmitter requirements include ACLR, spectrum emission mask, spurious emissions, and intermodulation, while the receiver requirements include ACS, blocking, spurious emissions, and intermodulation. These requirements are specified in TS 36.101 [3] and TS36.104 [4] for LTE UE and BS, respectively.

Conclusions

In this article, we have provided an overview of the coexistence studies performed in 3GPP RAN Working Group 4 for LTE with other mobile systems. We have described the terminologies commonly used in the coexistence studies, explained when and how deterministic analysis could be useful, given the simulation methodology and assumptions used in the system simulation, and provided some simulation results to show the system impacts when different system parameters are used.

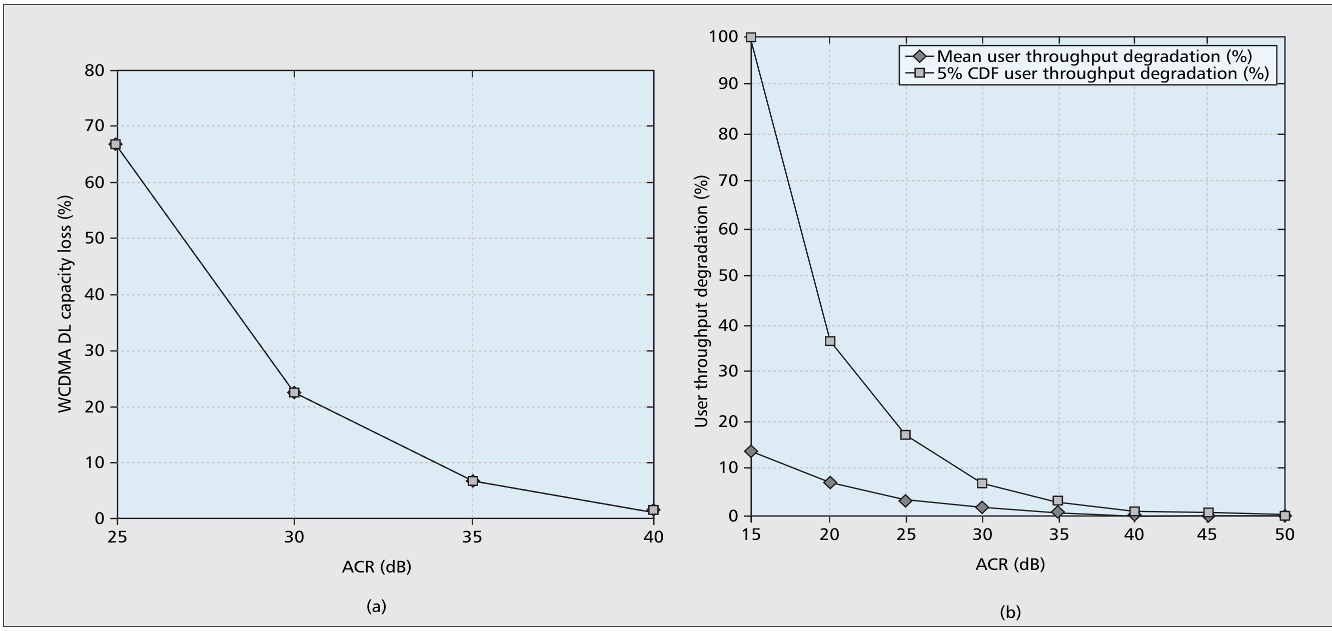
References

[1] 3GPP TS 25.942, "Radio Frequency (RF) System Scenarios," v. 7.0.0, Mar. 2007.
[2] 3GPP TR 36.942, Nokia Siemens Networks R4-071753, v. 1.4.0, Oct. 2007.
[3] 3GPP TS 36.101, "Evolved Universal Terrestrial Radio Access (LTE): User Equipment (UE) Radio Transmission and Reception," v. 8.2.0, May 2008.
[4] 3GPP TS 36.104, "Evolved Universal Terrestrial Radio Access (LTE): Base Station (BS) Radio Transmission and Reception," v. 8.2.0, May 2008.

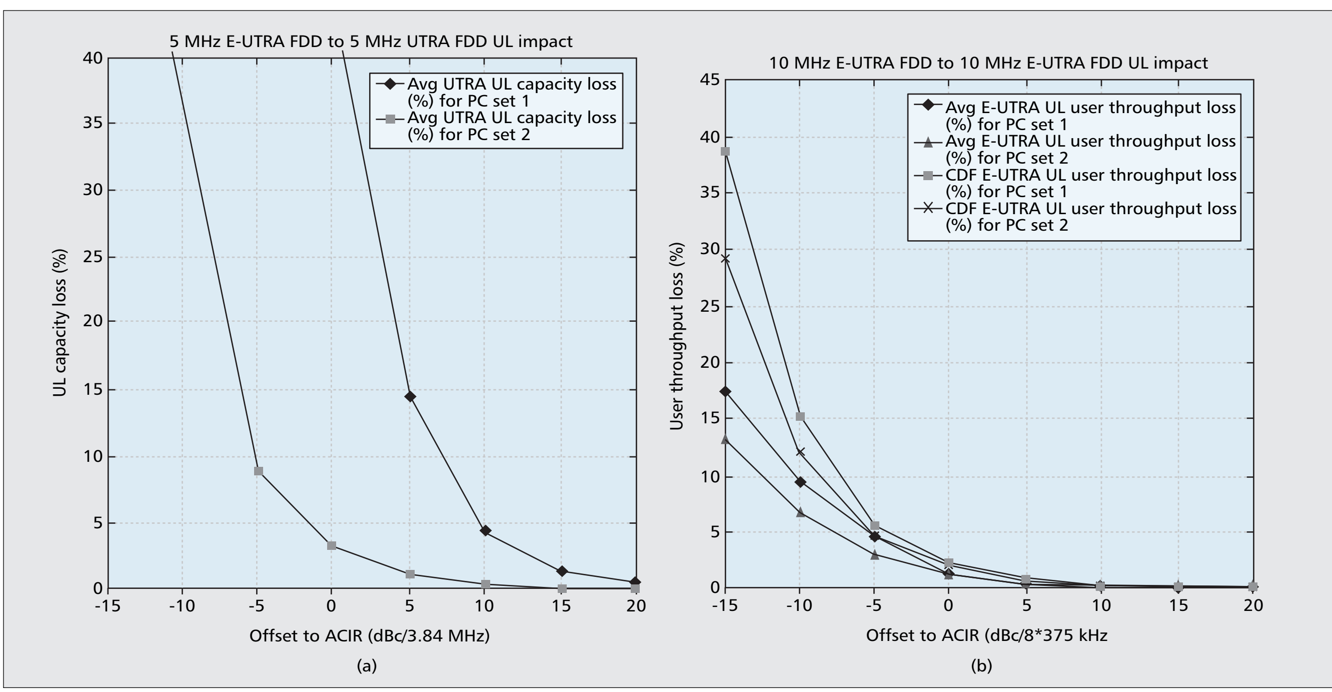
Biographies

Man-Hung Ng received a B.Sc. degree in Computer Studies from City University of Hong Kong in 1991. He worked as a computer programmer in Hong Kong from 1991 to 1995. In 1996 he obtained a M.Sc. degree in Communication and Radio Engineering from King's College London. He joined the University of Hong Kong as a research assistant in 1997, and completed a Ph.D. degree in mobile communications in 2001. He joined Lucent Technologies N.S. (now Alcatel-Lucent Telecom Limited) United Kingdom in 2001 and is now a principal standards engineer.

Shen-De Lin received his B.S. degree in electronics engineering from Fu Jen Catholic University in Taiwan in 1982, and his M.S. and Ph.D. degrees from State University of New York (SUNY) at Stony Brook, USA in 1987 and 1991, respectively. After graduating from SUNY, he jointed AT&T Bell Laboratories as a cellular system engineer and was promoted to the Consulting Member of Technical Staff in 2000. He has worked on a wide array of international cellular technologies and standards including analog, TDMA,



■ **Figure 3.** *DL throughput loss vs. ACIR with LTE BS interference: a) UMTS DL capacity loss vs. ACIR with 5 MHz LTE BS interference; b) 10 MHz LTE DL throughput loss vs. ACIR with 10 MHz LTE BS interference.*



■ **Figure 4.** *UL throughput loss vs. ACIR offset with LTE UE interference: a) 5 MHz UMTS UL capacity loss vs. ACIR offset with 5 MHz LTE UE interference; b) 10 MHz LTE UL throughput loss vs. ACIR offset with 10 MHz LTE UE interference.*

GSM, CDMA, WiMAX, and LTE. He has been responsible for wireless system performance evaluation , mobile system requirement definition, link budgets, inter-system interference study, and RF engineering guidelines. He has published seven technical papers and more than 100 internal technical memoranda. He gave a talk entitled "RF Filter Needs for Wireless Applications," at the *IEEE Microwave Theory and Techniques Workshop* in 1993. He held one patent regarding CDMA handoff. He is the co-author of the book *Handbook of CDMA System Design, Engineering, and Optimization* published by Prentice Hall in 2000.

JIMMY KWOK-ON LI received a B.S. degree in electrical engineering from the Rensselaer Polytechnic Institute in 1994, and an M.S. degree from the University of Southern California as a Hughes Master's Fellow in 1996. He is a systems engineer and has experience in modeling and analyzing various air-interface technologies in the field of satellite and mobile wireless communications. Prior to joining Lucent Technologies in 2000, he had his college internship at NASA Langley Research Center, and has worked for Hughes Space and Communications and ITT.

SAID TATESH received his B.Sc. degree in electrical engineering from the University of Damascus, Syria in 1988. In 1992 he received an M.Sc. degree in satellite communication from Surrey University, followed by a Ph.D. in mobile communications. He joined Alcatel-Lucent in 1997 where he worked on multiple projects, including the AMR codec, voice over GPRS, GERAN evolution, UMTS, and HSPA standardization. Currently, he heads the Radio Technology department responsible for UMTS/LTE standards. He and his team are actively working on the LTE air interface design and standardization in 3GPP.